Relational Database Design Theory Part II

CPS 116
Introduction to Database Systems

Announcements (October 12)

- Midterm graded; sample solution available
  - Please verify your grades on Blackboard
- Project milestone #1 due today

Review

- Functional dependencies
  - $X \rightarrow Y$: If two rows agree on X, they must agree on Y
  - ☞A generalization of the key concept
- Non-key functional dependencies: a source of redundancy
  - Non-trivial $X \rightarrow Y$ where X is not a superkey
  - ☞Called a BCNF violation
- BCNF decomposition: a method for removing redundancies
  - Given $R(X, Y, Z)$ and a BCNF violation $X \rightarrow Y$, decompose R into $R_1(X, Y)$ and $R_2(X, Z)$
  - ☞A lossless join decomposition
- Schema in BCNF has no redundancy due to FD's

Next

- 3NF (BCNF is too much)
- Multivalued dependencies: another source of redundancy
- 4NF (BCNF is not enough)

Motivation for 3NF

- *Address* (*street_address*, *city*, *state*, *zip*)
  - *street_address*, *city*, *state* → *zip*
  - *zip* → *city*, *state*
- Keys
  - {*street_address*, *city*, *state*}
  - {*street_address*, *zip*}
- BCNF?
  - Violation: *zip* → *city*, *state*

To decompose or not to decompose

$Address_1$ (*zip*, *city*, *state*)

$Address_2$ (*street_address*, *zip*)

- FD's in $Address_1$
  - *zip* → *city*, *state*
- FD's in $Address_2$
  - None!
- Hey, where is *street_address*, *city*, *state* → *zip*?
  - Cannot check without joining $Address_1$ and $Address_2$ back together
- Problem: Some lossless join decomposition is not dependency-preserving
- Dilemma: Should we get rid of redundancy at the expense of making constraints harder to enforce?

3NF

- R is in Third Normal Form (3NF) if for every non-trivial FD $X \rightarrow A$ (where A is single attribute), either
  - X is a superkey of R, or
  - A is a member of at least one key of R
  - ☞ Intuitively, BCNF decomposition on $X \rightarrow A$ would "break" the key containing A
- So *Address* is already in 3NF
- Tradeoff:
  - Can enforce all original FD's on individual decomposed relations
  - Might have some redundancy due to FD's

BCNF = no redundancy?

- *Student* (*SID*, *CID*, *club*)
  - Suppose your classes have nothing to do with the clubs you join
  - FD's?
    - None
  - BCNF?
    - Yes
  - Redundancies?
    - Tons!

SID	*CID*	*club*
142	CPS116	ballet
142	CPS116	sumo
142	CPS114	ballet
142	CPS114	sumo
123	CPS116	chess
123	CPS116	golf
...	...	...

Multivalued dependencies

- A multivalued dependency (MVD) has the form $X \twoheadrightarrow Y$, where X and Y are sets of attributes in a relation R
- $X \twoheadrightarrow Y$ means that whenever two rows in R agree on all the attributes of X, then we can swap their Y components and get two new rows that are also in R

X	*Y*	*Z*	
a	*b1*	*c1*	
a	*b2*	*c2*	
a	*b1*	*c2*	Must be in R too
a	*b2*	*c1*	Must be in R too
...	...	...	

MVD examples

Student (*SID*, *CID*, *club*)

- $SID \twoheadrightarrow CID$
- $SID \twoheadrightarrow club$
  - Intuition: given *SID*, *CID* and club are "independent"
- $SID, CID \twoheadrightarrow club$
  - Trivial: LHS $\cup$ RHS = all attributes of R
- $SID, CID \twoheadrightarrow SID$
  - Trivial: LHS $\supseteq$ RHS

Complete MVD + FD rules

- FD reflexivity, augmentation, and transitivity
- MVD complementation:
  If $X \twoheadrightarrow Y$, then $X \twoheadrightarrow attrs(R) - X - Y$
- MVD augmentation:
  If $X \twoheadrightarrow Y$ and $V \subseteq W$, then $XW \twoheadrightarrow YV$
- MVD transitivity:
  If $X \twoheadrightarrow Y$ and $Y \twoheadrightarrow Z$, then $X \twoheadrightarrow Z - Y$
- Replication (FD is MVD):
  If $X \rightarrow Y$, then $X \twoheadrightarrow Y$
- Coalescence:
  If $X \twoheadrightarrow Y$ and $Z \subseteq Y$ and there is some W disjoint from Y such that $W \rightarrow Z$, then $X \rightarrow Z$

Try proving things using these!

An elegant solution: chase

- Given a set of FD's and MVD's $\mathcal{D}$, does another dependency d (FD or MVD) follow from $\mathcal{D}$?
- Procedure
  - Start with the hypothesis of d, and treat them as "seed" tuples in a relation
  - Apply the given dependencies in $\mathcal{D}$ repeatedly
    - If we apply an FD, we infer equality of two symbols
    - If we apply an MVD, we infer more tuples
  - If we infer the conclusion of d, we have a proof
  - Otherwise, if nothing more can be inferred, we have a counterexample

Proof by chase

❖ In $R(A, B, C, D)$, does $A \twoheadrightarrow B$ and $B \twoheadrightarrow C$ imply that $A \twoheadrightarrow C$?

Have

A	B	C	D
a	b1	c1	d1
a	b2	c2	d2

$A \twoheadrightarrow B$

A	B	C	D
a	b2	c1	d1
a	b1	c2	d2

$B \twoheadrightarrow C$

A	B	C	D
a	b2	c1	d2
a	b2	c2	d1

$B \twoheadrightarrow C$

A	B	C	D
a	b1	c2	d1
a	b1	c1	d2

Need

A	B	C	D
a	b1	c2	d1
a	b2	c1	d2

Another proof by chase

❖ In $R(A, B, C, D)$, does $A \rightarrow B$ and $B \rightarrow C$ imply that $A \rightarrow C$?

Have

A	B	C	D
a	b1	c1	d1
a	b2	c2	d2

$A \rightarrow B$ $\quad b1 = b2$

$B \rightarrow C$ $\quad c1 = c2$

Need

$c1 = c2$

In general, both new tuples and new equalities may be generated

Counterexample by chase

❖ In $R(A, B, C, D)$, does $A \twoheadrightarrow BC$ and $CD \rightarrow B$ imply that $A \rightarrow B$?

Have

A	B	C	D
a	b1	c1	d1
a	b2	c2	d2

$A \twoheadrightarrow BC$

A	B	C	D
a	b2	c2	d1
a	b1	c1	d2

Counterexample!

Need

$b1 = b2$

4NF

❖ A relation R is in Fourth Normal Form (4NF) if
- For every non-trivial MVD $X \twoheadrightarrow Y$ in R, X is a superkey
- That is, all FD's and MVD's follow from "key $\rightarrow$ other attributes" (i.e., no MVD's, and no FD's besides key functional dependencies)

❖ 4NF is stronger than BCNF
- Because every FD is also a MVD

4NF decomposition algorithm

❖ Find a 4NF violation
- A non-trivial MVD $X \twoheadrightarrow Y$ in R where X is not a superkey

❖ Decompose R into R_1 and R_2, where
- R_1 has attributes $X \cup Y$
- R_2 has attributes $X \cup Z$ (Z contains attributes not in X or Y)

❖ Repeat until all relations are in 4NF

❖ Almost identical to BCNF decomposition algorithm

❖ Any decomposition on a 4NF violation is lossless

4NF decomposition example

SID	CID	club
142	CPS116	ballet
142	CPS116	sumo
142	CPS114	ballet
142	CPS114	sumo
123	CPS116	chess
123	CPS116	golf
...	...	...

Student (*SID*, *CID*, *club*)

4NF violation: $SID \twoheadrightarrow CID$

Enroll (*SID*, *CID*)

4NF

SID	CID
142	CPS116
142	CPS114
123	CPS116
...	...

Join (*SID*, *club*)

4NF

SID	club
142	ballet
142	sumo
123	chess
123	golf
...	...

3NF, BCNF, 4NF, and beyond

Anomaly/normal form	3NF	BCNF	4NF
Lose FD's?	No	Possible	Possible
Redundancy due to FD's	Possible	No	No
Redundancy due to MVD's	Possible	Possible	No

- Of historical interests
  - 1NF: All column values must be atomic
  - 2NF: Slightly more relaxed than 3NF

Summary

- Philosophy behind BCNF, 4NF:
  Data should depend on the key, the whole key, and nothing but the key!
- Philosophy behind 3NF:
  … But not at the expense of more expensive constraint enforcement!